AFRL-HE-BR-TR-2006-0074

IN SEARCH OF CIRCASEMIDIAN RHYTHMS

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November 2006

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20061205004

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
1-25-2006	Technical Report	4-1-2004 to 1-30-2005

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
In Search of Circasemidian Rhythms	F33615-00-C-6013

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
James C. Miller, Ph.D	

5e. TASK NUMBER

5f. WORK UNIT NUMBER
7757P905

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT
AFRL/HEPF 2485 Gillingham Dr, Bldg 170 Brooks City-Base, Texas 78235	

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	AFRL/HEPF

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-BR-TR-2006-0074

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
ultradian rhythm, circadian rhythm, cosine curve fit, cosinor analysis, body temperature, sleepiness, response time, memory scanning rate

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Dr. James C. Miller
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED	UNCLAS	24	19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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PREFACE

SUMMARY

There is controversy over the existence of physiological or behavioral circasemidian (12-h period) rhythms. However, a number of reports have shown a circasemidian error pattern in industrial and transportation environments and a circasemidian pattern in body temperature. To help us quantify the effects of fatigue, we hypothesized that body temperature, subjective sleepiness, simple response time and working memory speed would oscillate with a period of 12 hours (the circasemidian frequency); and that the parameter values describing the circasemidian oscillations of the measures would differ across genders and age groups. Measurements were acquired from 37 male and female subjects at half-hourly intervals from 0700h to 1900h in constant conditions. Circasemidian cosine curves were fitted to the data of individual subjects by the least-squares method. A statistically-significant, 12-hour pattern was found for body temperature and for subjective sleepiness, but not for simple response time or working memory speed. No differences were found with respect to gender or age group. Body temperature peaked at 16:49h and sleepiness peaked at 17:40h. Considering the large numbers of field observations of a two-peak pattern in errors and accidents, the failure to detect a circasemidian rhythmicity in task performance was attributed to the nature of task, itself. Future investigations should attempt to replicate our findings, acquire 24 h/day body temperature data, combine circasemidian with circadian cosinor estimates, determine which laboratory tasks display a circasemidian rhythmicity, try to determine why only some tasks may display that rhythmicity, and consider models other than the cosine curve.

INTRODUCTION

There is controversy over the existence of physiological and behavioral circasemidian rhythms (rhythms with a periodicity of 12 hours; Mitler 1989). No evidence exists to support the presence of a circasemidian rhythm in the rhythmic cells of the suprachiasmatic nucleus, the accepted internal timing source for the major circadian rhythms of the body. However, a number of published data sets have shown a daily two-peak error pattern in industrial and transportation environments (Bjerner et al. 1955; Browne 1949; Folkard et al. 2005; Harris 1977, 1978; Hildebrandt et al., 1974; Kogi & Ohta 1975; Langlois et al. 1985; Lavie et al. 1986; Mitler 1989; Prokop & Prokop 1955). The pattern was also obvious in many of the charts shown in the review by Rutenfranz and Colquhoun (1979), though they did not suggest a circasemidian rhythm as a mediator for the pattern. Other investigators have reported a circasemidian rhythm in body temperature (Colquhoun et al. 1968, 1978; Martineaud et al. 2000), melatonin (Maggioni et al. 1999) and slow-wave sleep (Hayashi et al. 2002).

These behavioral and physiological observations supported the need to consider a 12-h rhythmicity in the quantification of daily variations in physiology and some kinds of behavior in our fatigue modeling efforts (Hursh et al. 2004). As an initial effort along these lines, we simply questioned whether we could replicate some of these findings in our laboratory. We hypothesized that:

> h_1: Body temperature, subjective sleepiness, simple response time and working memory speed will oscillate with a period of 12 hours (the circasemidian frequency).

> h_2: The parameter values describing the circasemidian oscillations of body temperature, subjective sleepiness, simple response time and working memory speed will differ across genders and age groups.

METHODS

The research objectives were to measure human physiological, subjective and behavioral circasemidian rhythmicities during daytime hours under relatively constant environmental conditions, and to describe them quantitatively with respect to gender and age. Data were to be acquired from four gender-age cells. Cell assignments were determined by subject gender and age (18-39 years or 40-62 years), with 17 subjects per cell (68 subjects, total). Descriptive analyses were to be conducted within cells (repeated measures) and limited comparisons were made across cells (independent groups).

Due to operational constraints in the laboratory, data acquisition ceased with 17 subjects assigned to the younger male cell, 10 in the older male cell, 8 in the younger female cell and 2 in the older female cell. Fortunately, the ages of the 2 subjects in the latter cell were quite close to the younger cell. Thus, all female subjects were combined into a single female cell of 10 subjects ranging in age from 18 to 46 years. The mean age of the female group was quite similar to that of the younger male group.

SUBJECTS

The protection of human subjects and informed consent procedures were assessed by the Institutional Review Board at Brooks City-Base, Texas, and approved. The subjects were not paid. Potential subjects who were frequent smokers were asked to self-eliminate. Potential subjects were also provided with a voluntary medical screening form that discouraged those taking stimulant or depressant medications or who knew that they had been diagnosed with sleep pathology from enrolling as research subjects. Due to privacy issues, we were unable to determine the numbers of self-eliminations that occurred on the bases of these restrictions.

Excessive daytime sleepiness (EDS) and obesity were exclusionary criteria. The subjects needed to remain awake throughout each day of data acquisition, and EDS would have interfered with data acquisition and subsequent data quality. The Epworth Sleepiness Scale (ESS) was used to screen for EDS (Johns 1991,1992). An ESS score above 15 was disqualifying. Obesity is associated with sleep apnea, which is, in turn, associated with EDS (Aldrich et al. 2000). Obesity was quantified as body mass index (BMI). An investigator verified height and weight without shoes in the laboratory and calculated the BMI using the international standard (ACSM 2000; NIH 1998; WHO 1998). With one exception (a weight lifter), a BMI greater than 30 was disqualifying.

The subject characteristics are reported in Table I. The mean age of the older male group differed significantly from the mean ages of the other two groups by t test ($p < 0.01$). The mean estimated BMI of the younger male group was significantly greater than the mean estimated BMI of the female group ($p < 0.01$). The mean educational level of the older male group was significantly greater than the mean educational level of the other two groups ($p < 0.05$).

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Table I. Subject characteristics: mean (sd). All self-reported except for body mass index (BMI). Education level: 1 = high school completion, 2 = Associate, 3 = Bachelor, 4 = Master, 5 = Doctorate. *p<0.05, **p < 0.01 (see text).

	Younger Males (n = 17)	Older Males (n = 10)	Females (n = 10)
Age (yrs)**	29.4 (6.7)	51.1 (6.8)	28.5 (9.4)
BMI Estimate**	26.9 (3.0)	25.2 (2.5)	23.3 (3.1)
ESS Score	5.9 (2.5)	6.2 (4.1)	5.6 (1.6)
No. Tobacco Users	1	1	0
No. Alcohol Users	10	6	9
Alcoholic Drinks/Week	2.3 (2.8)	2.4 (3.3)	2.9 (2.4)
No. Caffeine Users	14	10	8
Caffeine Drinks/Day	1.6 (1.1)	2.7 (1.8)	1.3 (1.1)
No. Military	13	8	4
Education Level*	2.5 (1.5)	3.9 (1.0)	2.9 (1.0)

VARIABLES

Body temperature was documented by self-measurement of tympanic membrane temperature (T_{Ty}) as determined by an infrared probe (Braun Thermoscan; Beach & McCormick 1991; Smith & Fehling 1996). The Thermoscan was a small, hand-held infrared probe shaped like an otoscope. Using a remote infrared sensor, it measured body temperature near the brain, as represented by the temperature of the blood flowing through microscopic vessels in the tympanic membrane.

The measurement method had been determined by trial and error, augmented by discussions with the manufacturer and reviews of pertinent research articles (Beach & McCormick 1991; Miller et al. 1999; Wylie et al. 1996). First, the individual reached over his or her head with one hand, grasped the top of the ear and executed the "ear tug" used with clinical otoscopes. The tug was essential: it tended to straighten the ear canal, allowing the sensor to be aimed at the tympanic membrane instead of at surrounding, cooler tissues. With the other hand, the subject (1) inserted the sensor housing with a clean, disposable, plastic cover into the ear canal; (2) rotated it about 1/4 turn to seat it; (3) pressed the sensing button and held it down for at least the one second needed for a reading; (4) removed the device from the ear and noted the temperature; (5) discarded the used cover and acquired a new cover; and (6) repeated the maneuver to get a second reading. The individual then recorded the higher of the two readings. Taking more than two readings appeared to induce unwanted cooling in the ear canal.

The perceptual dimension, sleepiness, was used to assess research subjects' overlapping perceptions of sleepiness, fatigue and alertness (Mackie & Miller 1978). Various Likert-type sleepiness scales, especially the Stanford and Karolinska scales, had been used extensively in field and laboratory studies. The Visual Analog Sleepiness Scale (VASS) was used here to acquire subjective estimates of sleepiness (Figure 1). The VASS consisted of a 100-unit, anchored rating scale (for example, Sinclair 1995), sometimes called a visual analog scale. The VASS was anchored at both ends and the middle with

wakefulness-sleepiness descriptors from the Stanford Sleepiness Scale (SSS; Hoddes & Zarcone 1973). The descriptors were selected from the SSS (with the midpoint text modified slightly) on the basis of the recommendations by Horne (1991) that suggested parallelism with the alertness-sleepiness descriptors used for the "vigor" factor of the Profile of Mood States (POMS). The subject used the VASS by selecting a number from 1 to 100 with reference to the scale.

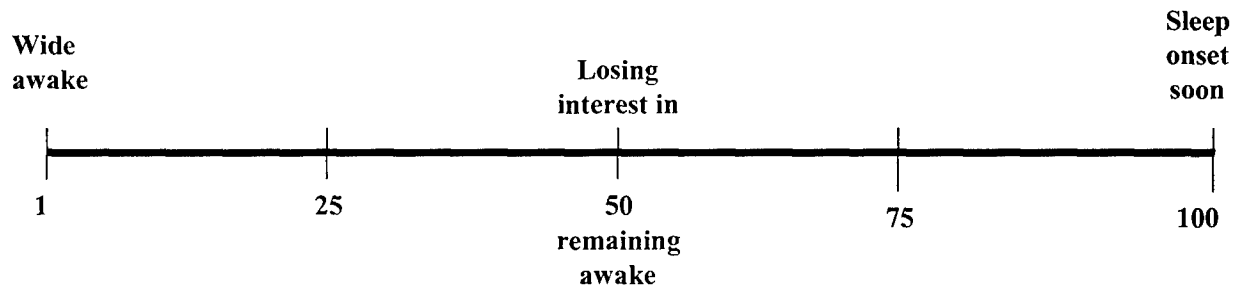| Wide awake		Losing interest in		Sleep onset soon
1	25	50 remaining awake	75	100

Figure 1. The visual analog sleepiness scale (VASS).

The Sternberg Memory Scanning Task (Sternberg 1969, 1975) was used to assess short-term memory function. It was run from within the Automated Neuropsychological Assessment Metrics system (ANAM, Naval Computer and Telecommunications Station, NAS Pensacola FL; Reeves 1997, 1998). Positive sets of 2, 4 and 6 letters were presented for memorization. The inter-stimulus interval ranged from 950 to 1150 msec and there was a total of 36 probe letters. The subject responded, yes or no, on the personal computer keyboard whether the test item was a member of the positive set. The intercept of the linear regression line for response times across the three set sizes provided an index of simple response time (SRT) in milliseconds (msec), while the slope of the line provided an estimate of memory scanning rate (MSR) in msec per item. The test was fully self-paced. Two training periods across two training days were used to allow the subjects to achieve reliable performance on the Sternberg task, and to introduce them to the other measurement techniques. The number of training trials varied across subjects; they were trained as needed to reach a reliable level of performance. Reliable performance on the Sternberg task was defined as repeated response accuracies above 95% and a range of mean response times of about 60 msec or less across the last several tests for the 2, 4 and 6-letter sets, respectively.

PROCEDURES

After the enrollment phase of recruiting, each subject's age, gender, BMI, and ESS were acquired and recorded. Training time was brief, approximately one hour across two days, since the procedures to be learned by the subjects were quite simple. Each subject spent one 12-h experimental day in the Fatigue Countermeasures Laboratory, Building 1192, Brooks City-Base, TX. Testing occurred in one of two counterbalanced and alternating orders: Sternberg letter sets (2, 4 and 6 letters), followed by the VASS and T_{Ty}, or Sternberg letter sets (6, 4 and 2 letters), followed by the VASS and T_{Ty}. Each test session took about four minutes.

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Measurements were acquired at half-hourly intervals from 0700h through 1900h on each day. Thus, there were 25 measurement periods per day. This testing frequency of 48 samples/day was determined primarily by the need to detect potential ultradian oscillations at 16 cycles per day (Broughton 1998) without allowing aliasing in other frequency analyses.

We controlled the experimental work demand, external distractions and stress, food intake, posture, ambient temperature, background noise, ambient lighting and the intake of confounders such as nicotine and caffeine (vanDongen & Dinges 2000). Each subject remained in a closed, access-controlled bedroom in the temporal isolation facility, where ambient background noise and light (approx. 100 lux) were quite low and constant, and distractions were quite rare. They always assumed a sitting posture at a personal computer for testing. They were fed on a quasi-random schedule throughout each experimental day to minimize the likelihood for evoked rhythmic effects of feeding cues that might mask or confound ultradian rhythms. There were six equal-portion feedings during the 12 hours. The inter-feeding interval ranged from 1 to 3 hours, starting with an initial feeding at 0700h. Each subject's maximum allowable total caloric intake was about 1.3x the predicted basal metabolic rate for the individual's gender, height and weight (International Commission 1975). Most took in many fewer calories. The day's diet was somewhat boring, consisting primarily of a nutritional drink (Ensure Plus, Abbott Laboratories), nutritional bars (Luna, Clif Bar Inc.) and water *ad lib*. For habitual caffeine users, up to about 200 mg was allowed between 07:00 and 08:00 on the experimental day.

To help minimize distractions and other masking effects, the subjects were not allowed to interact directly with others, except for randomly-timed interactions with study proctors, or indirectly by e-mail or telephone, to use video devices (games, movies), to listen to live-broadcast television or radio, to exercise, nor to have access to solar light. To minimize boredom and to help sustain motivation, they were allowed to read, to engage in computer work and to listen to music between test sessions.

DATA PROCESSING

Four measures were examined for each of the 3 subject samples: T_{Ty}, VASS, SRT, and MSR. Cosinor analysis was used to characterize circasemidian rhythmicity for each variable, within subjects, using the equations of Halberg *et al.* (1972). The equations were implemented in a Microsoft® Office Excel 2003 spreadsheet and the oscillation rate was set to 4π radians/day. The spreadsheet's Solver function was used to minimize the residual sum of squares of the cosine function estimates by manipulating the cosinor midline (mesor) and the amplitude-weighted, 24-hour-period sine and cosine of the relative phase of the estimated function. The output of the cosinor analysis for each time series included mesor, (half-wave) amplitude, relative waveform phase (peak time), standard error of the estimate, squared Pearson correlation coefficient (r^2), F ratio, mean squared error for F, and degrees of freedom. If the peak time was reported to occur within the midnight to noon period, it was adjusted to the noon to midnight period by adding 12 hours. This adjustment removed spurious variability due to the semi-daily

peak of a circasemidian rhythmicity. The F ratio provided a test statistic for h_0, amplitude = 0 (*op. cit.*), for each individual time series. The population parameter estimates of amplitude and phase for each data sample were assessed graphically as a polar, clock-face representation on a rectangular grid with a 95% confidence ellipse. The non-overlap of confidence ellipses from two samples indicated a successful two-tailed test for rejection of h_0, sample 1 = sample 2, for amplitude and relative phase. Statistical significance was accepted at the 95% level of confidence ($p < 0.05$).

The reader should note the use of the word "rhythmicity" in this report. We did not use a procedure that would discriminate the existence of an endogenous circasemidian "rhythm" from a circasemidian harmonic of the circadian rhythm. A more sophisticated experimental procedure, such as one that would allow one rhythm to dissociate from the other, would be required to establish the presence of a circasemidian rhythm.

RESULTS

BODY TEMPERATURE (T_{Ty})

Visual inspection of data scatterplots provided compelling evidence of the presence of a circasemidian rhythmicity in T_{Ty} for many subjects (for example, Figure 2). The mean cosinor amplitude and peak time were 0.31 °F at 17:01h for the younger male group, respectively (Figure 3), and the mean amplitude was statistically significant ($F(2,23) = 7.24$, MSE = 0.126, $p < 0.01$; Table II). The mean cosinor amplitude and peak time were 0.40 °F at 17:10h for the older male group, respectively, and the mean amplitude was statistically significant ($F(2,23) = 5.89$, MSE = 0.265, $p < 0.01$). The mean cosinor amplitude and peak time were 0.32 °F at 16:09h for the female group, respectively, and the mean amplitude was statistically significant ($F(2,23) = 5.89$, MSE = 0.153, $p < 0.01$). The overlaps among the three error ellipses indicated no statistically significant differences in cosinor amplitude or peak time among the three groups. The mean cosinor amplitude and peak time were 0.34 °F at 16:49h for the combined groups, respectively, and the mean amplitude was statistically significant (mean $F(2,23) = 6.51$, mean MSE = 0.171, $p < 0.01$).
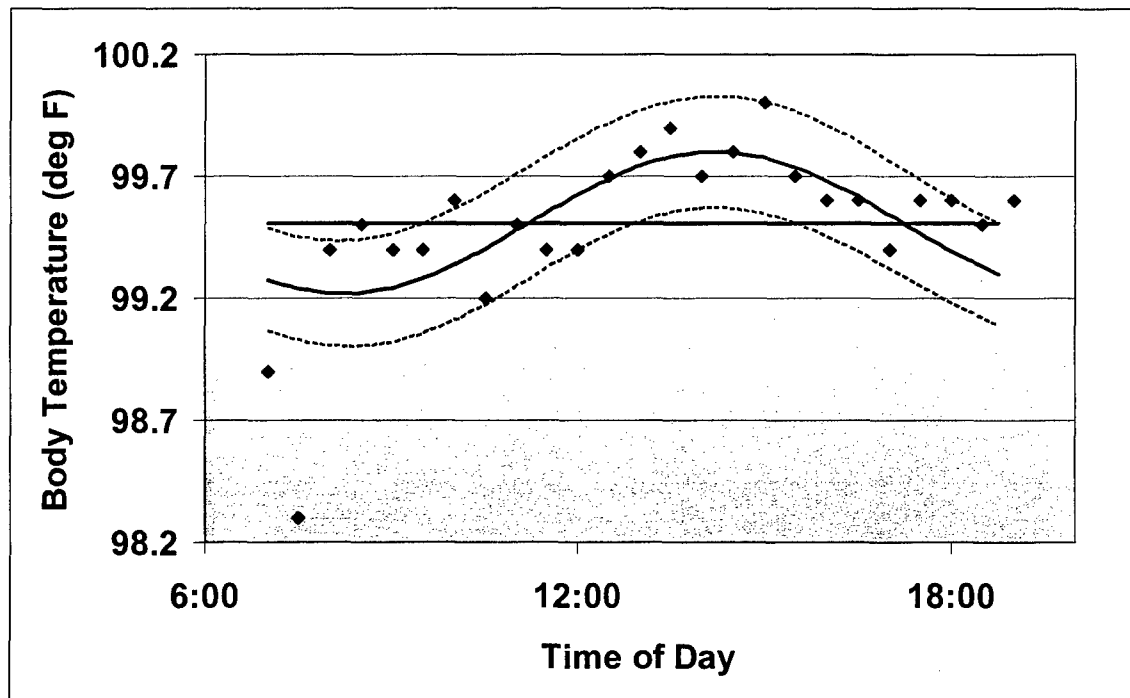

Figure 2. Example of raw data scatterplot for one younger male subject, with fitted circasemidian curve and 95% confidence interval. Mesor = 99.5 deg F, amplitude = 0.29 deg F, peak time = 14:13h, SEE = 0.16 deg F, $r^2 = 0.391$, $F(2,23) = 7.05$ ($p < 0.05$ for amplitude), MSE = 0.075 deg F.

SLEEPINESS RATING (VASS)

The mean cosinor amplitude and peak time were 7.66 scale units at 18:06h for the younger male group, respectively, and the mean amplitude was statistically significant $(F_{(2,23)} = 13.88$, MSE = 59.95, $p < 0.01)$. The mean cosinor amplitude and peak time were 8.21 units at 17:17h for the older male group, respectively, and the mean amplitude was statistically significant $(F_{(2,23)} = 8.50$, MSE = 66.67, $p < 0.01)$. The mean cosinor amplitude and peak time were 7.28 units at 17:18h for the female group, respectively, and the mean amplitude was statistically significant $(F_{(2,23)} = 12.60$, MSE = 51.50, $p < 0.01)$. The overlaps among the three error ellipses indicated no statistically significant differences in cosinor amplitude or peak time among the three groups. The mean cosinor amplitude and peak time were 7.71 units at 17:40h for the combined groups, respectively, and the mean amplitude was statistically significant (mean $F_{(2,23)} = 12.08$, mean MSE = 59.48, $p < 0.01)$.

Table II. Sample and grand mean values for cosinor parameters. Sample sizes were 17, 10, 10, and 37 for younger males, older males, females, and the combined groups, respectively, with 25 observations per subject. SEE = standard error of the estimate; MSE = mean squared error for F. ***$p < 0.01$ for amplitude.

| Measures	Means						
	Mesor	Half-wave Amplitude	Phase Time	SEE	r^2	F(2,23)	MSE
Body Temperature	(deg F)	(deg F)	(hrs)	(deg F)			(deg F)
Younger Males	98.25	0.309	17:01	0.176	0.336	7.24***	0.126
Older Males	97.89	0.403	17:10	0.233	0.292	5.89***	0.265
Females	98.71	0.325	16:09	0.189	0.311	5.89***	0.153
Combined Groups	98.28	0.339	16:49	0.195	0.317	6.51***	0.171
Sleepiness	(units)	(units)	(hrs)	(units)			(units)
Younger Males	22.05	7.66	18:06	3.45	0.404	13.88***	59.95
Older Males	22.23	8.21	17:17	4.32	0.379	8.50***	66.67
Females	12.99	7.28	17:18	3.76	0.450	12.60***	51.50
Combined Groups	19.65	7.71	17:40	3.77	0.410	12.08***	59.48
Response Time	(msec)	(msec)	(hrs)	(msec)			(msec)
Younger Males	312.8	38.43	19:29	25.24	0.142	2.02	8113.6
Older Males	334.5	38.54	21:02	26.02	0.110	1.60	10386.5
Females	319.0	28.42	18:33	19.41	0.101	1.45	7006.0
Combined	320.4	35.75	19:39	23.88	0.122	1.75	8428.4
Slope (MSR)	(msec/item)	(msec/item)	(hrs)	(msec/item)			(msec/item)
Younger Males	63.03	11.37	17:50	7.55	0.128	1.79	774.2
Older Males	81.41	13.93	17:03	9.15	0.140	2.18	1074.8
Females	60.43	9.35	17:16	6.44	0.108	1.47	755.9
Combined Groups	67.29	11.52	17:28	7.68	0.126	1.81	850.5
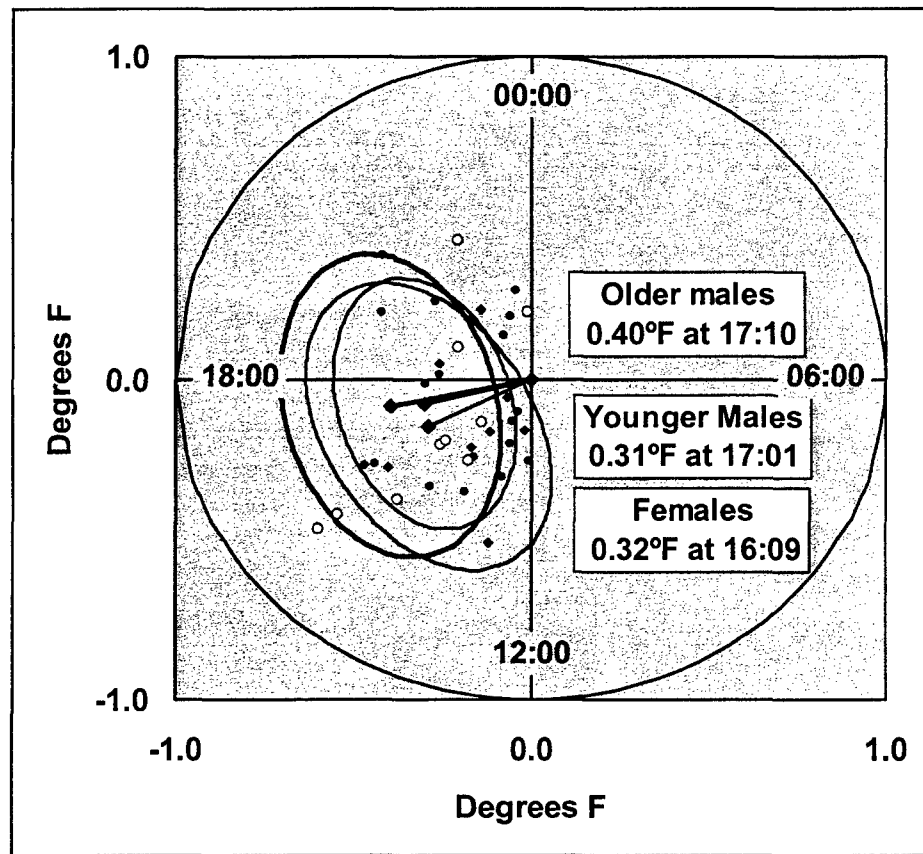
Figure 3. Polar (clockface) representation on a rectangular grid of circasemidian rhythmicity population parameter estimates (amplitude and peak time) and the overlapping 90% confidence ellipses for body Temperature (T_{Ty}) for older males (top left ellipse, n = 10, 0.40 °F amplitude at 17:10), younger males (middle ellipse, n = 17, 0.31 °F, 17:01) and females (lowest ellipse, n = 10, 0.32 °F at 16:09).

SIMPLE RESPONSE TIME (SRT)

The mean cosinor amplitude and peak time were 38.43 msec at 19:29h for the younger male group, respectively, but the mean amplitude was not statistically significant ($F_{(2,23)}$ = 2.02, MSE = 8113.6, p > 0.05). The mean cosinor amplitude and peak time were 38.54 msec at 21:02h for the older male group, respectively, but the mean amplitude was not statistically significant ($F_{(2,23)}$ = 1.60, MSE = 10386.5, p > 0.05). The mean cosinor amplitude and peak time were 28.42 msec at 18:33h for the female group, respectively, but the mean amplitude was not statistically significant ($F_{(2,23)}$ = 1.45, MSE = 7006.0, p > 0.05). The overlaps among the three error ellipses indicated no statistically significant differences in cosinor amplitude or peak time among the three groups. The mean cosinor amplitude and peak time were 35.75 msec at 19:39h for the combined groups, respectively, but the mean amplitude was not statistically significant (mean $F_{(2,23)}$ = 1.75, mean MSE = 8428.4, p > 0.05).

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MEMORY SCANNING RATE (MSR)

The mean cosinor amplitude and peak time were 11.37 msec/item at 17:50h for the younger male group, respectively, but the mean amplitude was not statistically significant ($F(2,23) = 1.79$, MSE = 774.2, $p > 0.05$). The mean cosinor amplitude and peak time were 13.93 msec/item at 17:03h for the older male group, respectively, but the mean amplitude was not statistically significant ($F(2,23) = 2.18$, MSE = 1074.8, $p > 0.05$). The mean cosinor amplitude and peak time were 9.35 msec/item at 17:16h for the female group, respectively, but the mean amplitude was not statistically significant ($F(2,23) = 1.47$, MSE = 755.9, $p > 0.05$). The overlaps among the three error ellipses indicated no statistically significant differences in cosinor amplitude or peak time among the three groups. The mean cosinor amplitude and peak time were 11.52 msec/item at 17:28h for the combined groups, respectively, but the mean amplitude was not statistically significant (mean $F(2,23) = 1.81$, mean MSE = 850.5, $p > 0.05$).

DISCUSSSION

Our hypothesis that body temperature, subjective sleepiness, simple response time and working memory speed would oscillate with a period of 12 hours (the circasemidian frequency) was supported in part: a 12-hour curvilinear pattern was found for body temperature and for subjective sleepiness, but not for simple response time or working memory scanning rate. Our hypothesis that the parameter values describing the circasemidian oscillations of body temperature, subjective sleepiness, simple response time and working memory speed would differ across genders and age groups was not supported.

The detection of a 12-hour pattern in body temperature was consistent with other reports: Colquhoun *et al.* (1968, 1978) examined the physiological circadian rhythm during maritime watchstanding. Seeking normative values, they looked back upon hourly body temperature readings taken from 59 young, healthy Navy personnel who were not standing watches and were sleeping normally at night (*op. cit.*). They fitted the group mean data with 24- and 12-hour sine and cosine curves (harmonic analysis), explaining 99% of the variance in the group mean data with the combination of the fundamental (24-h period) and first harmonic (12-h period). The resulting, complex curve was composed of a 24-h-period waveform with acrophase at 1700h and amplitude 1.06 deg F. The peak of the combined curve occurred at 2000h and the amplitude was 1.20 deg F. The minima of the fundamental and combined curves occurred at 0500h and 0400h, respectively. The combined curve was taken to represent the normal, underlying pattern of circadian-plus-circasemidian variation in body temperature.

In their earlier studies, Colquhoun *et al.* had noted circadian rhythm flattening. Now, they had the opportunity to collect temperature data (at 3-h intervals) from eight submarine sonarmen during a 48-day cruise (9). The sonarmen worked the traditional maritime 1-in-3, 4-h watch system that repeated every 72 hours. Harmonic analysis (fixed 24- and 12-h-period cosine curve fits) was attempted for each of 16 contiguous, 72-h cycles (16 cycles x 3 days/cycle = 48 days) for the 8 sonarmen (16 cycles x 8 sonarmen = 128 data samples). Good fits for the 24-h period, fundamental harmonic were achieved in only 68% of these 128 samples. When the first-harmonic, circasemidian curve was added to the fundamental, circadian curve, good curve fits were achieved in 88% of the samples. The inability to achieve good fits in more than 88% of the cases was attributed to a gradually increasing prevalence of circadian desynchrony among the subjects, induced by the maritime watchstanding schedule.

Our failures to detect the circasemidian rhythmicity in either response time or memory scanning rate were not expected in view of error and performance patterns observed by others in the field. To place our results in context, we focus briefly here on three field data sets, all with data reported at hourly intervals. The first set was from a relatively simple and safe task, the reading of gas meters. Bjerner *et al.* (1955) reported the hour-to-hour distribution of more than 75,000 meter reading errors across the 24-h period. The second data set was from a relatively complex and risky task, automobile driving (Mitler 1989). Mitler compiled the hour-to-hour distribution of more than 6,000 fatigue-related

traffic accidents across the 24-h period. Finally, Folkard *et al.* (2005) reported real-job speed and accuracy measures across the hours of the day, combined across three field studies conducted in industry.

For the present discussion, we used the cosinor method described above to fit cosine curves to these three data sets (estimated from published graphs) to determine how the addition of the first harmonic (12-h period; the circasemidian rhythmicity) might affect the goodness of fit of the fundamental (24-h period; the circadian rhythm). For the pattern of meter-reading errors, the 24-h-period curve explained 34.9% of the variance in the raw data while the combination of the fundamental and first harmonic waves explained 80.8% of the variance. For the pattern of fatigue-related traffic accidents, the 24-h-period curve explained 68.3% of the variance while the combination of the fundamental and first harmonic waves explained 96.3% of the variance. For real-job speed and accuracy, the 24-h-period curve explained 65.2% of the variance while the combination of the fundamental and first harmonic waves explained 83.9% of the variance.

Obviously, the first harmonic was quite useful in explaining the variance observed among these real-world error data just as it had been useful to Colquhoun *et al.* in explaining variance among observations of body temperature. This observation suggested that our selection of the Sternberg Memory task may have caused our failure to detect a circasemidian rhythmicity in task performance. Since the Sternberg task can be reliable (for example, Neubauer et al. 2000), it is likely that the speed at which memory scanning occurs and simple response time were not primary factors in the real-world errors described in the literature cited here.

It is extremely common for an oscillator to be affected by external factors that set up harmonic frequencies in its expression. This may be the case in the expression of the fundamental human circadian rhythm and a circasemidian first harmonic. Alternatively, Broughton (1998) proposed that the two-peak pattern may be explained by an interaction of (1) the expression of the GABA-ergic circadian arousal system that is based in the SCN and responsive to light and to the alertness-enhancing drug, modafinil, with (2) Process-S of the now classic 2-process model of arousal and alertness.

The acquisition of only 12 hours of data preclude any definitive conclusions about the existence of circasemidian rhythm in body temperature and subjective sleepiness. One needs data from two or more cycles of a rhythm to describe it accurately. Studies published by other laboratories (Colquhoun et al. 1968, 1978; Martineaud et al. 2000) have established the presence of circasemidian rhythm in body temperature. However, our failure to find any evidence in this preliminary, 12-hour study of a curvilinear function that suggested the presence of a circasemidian rhythmicity in either response time or memory scanning rate was unexpected.

The circasemidian rhythm had been observed to occur in a number of laboratory tasks involving working memory (Hursh et al. 2004) and in numerous industrial and transportations tasks (list cited in the Introduction). We assumed that a test designed to

assess short-term memory would also display a circasemidian rhythm. Our failures to detect circasemidian rhythmicity in either response time or memory scanning rate precluded any thought of applications to or modifications of existing methods for quantitatively estimating fatigue effects on cognitive performance (i.e., Hursh et al. 2004).

Future investigations should (1) attempt to replicate our findings; (2) acquire 24 h/day body temperature data, and combine circasemidian with circadian cosinor estimates; (3) determine which laboratory tasks display a circasemidian rhythmicity, and try to determine why only some tasks may display that rhythmicity; and (4) consider models other than the cosine curve.

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AFRL-HE-BR-TR-2006-0074

IN SEARCH OF CIRCASEMIDIAN RHYTHMS

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JANUARY 2005
01 April 2004 to 30 January 2005

Air Force Research Laboratory
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ADA 458153

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REPORT DOCUMENTATION PAGE

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
1-25-2006	Technical Report	4-1-2004 to 1-30-2005

4. TITLE AND SUBTITLE
In Search of Circasemidian Rhythms

5a. CONTRACT NUMBER
F33615-00-C-6013

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James C. Miller, Ph.D

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
7757P905

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AFRL/HEPF
2485 Gillingham Dr, Bldg 170
Brooks City-Base, Texas 78235

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Materiel Command

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HEPF

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-BR-TR-2006-0074

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES
09-22-06 Cleared for public release: PA-06-330

14. ABSTRACT
There is controversy over the existence of physiological or behavioral circasemidian (12-h period) rhythms. However, a number of reports have shown a circasemidian error pattern in industrial and transportation environments and a circasemidian pattern in body temperature. To help us quantify the effects of fatigue, we hypothesized that body temperature, subjective sleepiness, simple response time and working memory speed would oscillate with a period of 12 hours (the circasemidian frequency); and that the parameter values describing the circasemidian oscillations of the measures would differ across genders and age groups. Measurements were acquired from 37 male and female subjects at half-hourly intervals from 0700h to 1900h in constant conditions. Circasemidian cosine curves were fitted to the data of individual subjects by the least-squares method. A statistically-significant, 12-hour pattern was found for body temperature and for subjective sleepiness, but not for simple response time or working memory speed. No differences were found with respect to gender or age group. Body temperature peaked at 16:49h and sleepiness peaked at 17:40h. Considering the large numbers of field observations of a two-peak pattern in errors and accidents, the failure to detect a circasemidian rhythmicity in task performance was attributed to the nature of task, itself. Future investigations should attempt to replicate our findings, acquire 24 h/day body temperature data, combine circasemidian with circadian cosinor estimates, determine which laboratory tasks display a circasemidian rhythmicity, try to determine why only some tasks may display that rhythmicity, and consider models other than the cosine curve.

15. SUBJECT TERMS
ultradian rhythm, circadian rhythm, cosine curve fit, cosinor analysis, body temperature, sleepiness, response time, memory scanning rate

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Dr. James C. Miller
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED	SAR	24	19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

2006 61205004

Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR (2004). Fatigue models for applied research in warfighting. *Aviat Space Environ Med*, 75(3), Section II, Supplement, pp. A44-A53.

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